Prototyping tangibles : exploring form and interaction

PETRELLI, Daniela <http://orcid.org/0000-0003-4103-3565>, DULAKE, Nick <http://orcid.org/0000-0003-1841-5848>, MARSHALL, Mark <http://orcid.org/0000-0002-8875-4813>, WILLOX, Matt <http://orcid.org/0000-0001-7437-5559>, CAPARRELLI, Fabio and GOLDBERG, Robin

Prototyping Tangibles: Exploring Form and Interaction

Daniela Petrelli, Nick Dulake, Mark Marshall, Matt Willox, Fabio Caparrelli
Sheffield Hallam University
153 Arundel Street, Sheffiled S1 2NU - UK
d.petrelli@.shu.ac.uk

Robin Goldberg
Institute for Visualization and Interactive Systems
University of Stuttgart
Pfaffenwaldring 5a, 70560 Stuttgart, Germany
robin.goldberg@informatik.uni-stuttgart.de

ABSTRACT
In order to better explore the opportunities for tangible interaction in new areas such as the home or cultural heritage sites, we used multiple rapidly-developed prototypes that take advantage of existing technology. Physical prototypes allow us to give form to ideas and to evaluate the integration of form and function, two core components of tangible interaction. We discuss potentials and pitfalls when using off-the-shelf digital devices (by embedding a device, cracking it open and building on it, or collating board and parts) through six prototypes developed in two studies. Hacking devices to materialize our ideas proved excellent for fast prototyping. Technology imposed constraints and prompted different design solutions than initially intended offering unexpected ways to engage. On the basis of this experience we outline a process and offer guidelines for the fast prototyping of tangible interactions.

Author Keywords
Tangible interaction; fast prototyping; user feedback.

ACM Classification Keywords
D.2.1 Elicitation methods; H.5.2 User Interfaces.

INTRODUCTION
Material objects and their form are important in tangible interaction [1, 10]. A known form can afford specific behaviours and interaction designers can take advantage of this when creating new tangibles. The critical point is how integrated form and function are [1, 9], as loose connections and arbitrary mappings can mislead users [9]. The potential and pitfall of the form factor are well known in industrial design and prototypes are regularly used to systematically explore different forms and details. The understanding of how the prototype will fit in its context of use progressively grows through this iterative cycle of making and evaluating. This view of prototypes as tools for thinking and learning is shared across disciplines as diverse as product/service design [3] and software development [6]. How the prototypes look and function depends on which aspect of the final product they mean to capture and the current stage in the design/development process [6, 8, 12]. Sketches, paper mockups and other forms for communication, such as video prototypes are extensively used in the early stages, but once past the brainstorming phase quickly built "throw-away prototypes" are less common.

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This paper discusses the value of physical prototypes as a means to explore new domains for tangibles. Physical prototypes enable designers to focus on form and function simultaneously and how the two integrate. However to be able to quickly try out many ideas the cost of prototyping (in both resources and time) must be low. In six examples from two different case studies we show how costs can be reduced by using consumer devices and off-the-shelf technology (such as sound recording and playback devices) to provide core functionalities. This approach allows us to take the function for granted and concentrate on the form factor. 3D printing and laser cutting are used to shape forms closer to the final product than those achievable with cardboard and therefore enable us to fully explore at an early stage how potential adopters would interact.

We first review prototyping in design and software development and discuss the advantages of using existing technology. The two case studies then show three types of prototype: embedding devices, cracking them open, and collating components. We conclude the paper reflecting on the process we followed and providing guidelines for a hands-on trial.

PROTOTYPING IN DESIGN AND COMPUTING
Prototyping is not a new idea. In computing prototyping has been discussed since the early 80s [6] and physical prototyping is as much a core part of traditional industrial design as it is of the newest service design [3]. There are many forms of prototypes. Floyd [6] lists exploratory prototypes (informal, offers alternatives, unstructured and messy, used to communicate, to be thrown away); experimental prototypes (a proposed solution to a problem); evolutionary prototypes (appear later in the development and is a nearly-complete system). Hounde and Hill [12] distinguish prototypes on the basis of what they capture and therefore what they can evaluate (implementation, role or look-and-feel); early prototypes focus on one aspect while later prototypes should integrate the three. Design [3, 14] shifts the attention from the product to the experience thus encompassing, beyond the person and the object/system, the context of use and factors like fun and pleasure. For

Brown [3] prototypes are not working models: their purpose is to give form to an idea, show its strengths and weaknesses and identify new directions. They must be created quickly so as not to interrupt the creative flow, and should feed back immediately for a new round of reflection and design. Despite their diverse approaches, all authors agree that prototypes facilitate communication across different disciplines and with users. They materialize tacit knowledge [14], clear possible misunderstandings [6], and show how the work progresses [3].

Research to understand prototyping in pervasive computing and tangible interaction is limited. Hartmann et al. [8] looked at hardware and software mashups in professionals and amateurs with the first group making use of existing technology to explore new ideas while for the second group it was a mean to go beyond their actual competence. Professionals aim to try ideas quickly, postponing aspects of efficiency, and see this work as disposable. Similar findings are in Brandt et al. [1]: opportunistic programmers used cut-and-past code techniques as a method for fast prototyping. The value is not in the code produced, but in the knowledge gained during the process.

More effort has been spent in developing toolkits for prototyping: to map functions to specific sensors [7], the hardware of a new device to a 3D form [18], to integrate form and interaction "in rough form" [13] or as simulation [11]. All these examples, however, tend to overlook the value of aesthetic: form, when considered [11, 13], is a cardboard and duck-tape mockup. Also, the use of a toolkit may constrain the creative thinking to what the toolkit itself allows us to build or to what the designer is able to do with it. With our approach we stay open to any form and any interaction and take advantage of existing technology in speeding up the process of prototyping tangibles.

WHY USING OFF-THE-SHELF TECHNOLOGY?

The most striking advantage offered by using exiting technology for prototyping is the small scale and light weight. People are used to powerful devices that fit in one's hand, but any attempt to build in such a small scale in the lab is destined to fail. Large-scale production takes advantage of optimized chip design and printing, the cost of which cannot be justified for just a few exemplars.

Second is robustness: devices made for the consumer market have to work reliably over time. To know that the technology will work robustly is an invaluable advantage for interaction designers who can concentrate on exploring and understanding how the integration of form and function affects interaction.

Limited creation cost is also of great advantage: buying off-the-shelf devices or dedicated small boards is cheap and saves much soldering time. This allows the creation of exemplars that can be given away to potential users for full appropriation, as in (Fig. 2). It also provides some sense of the final cost, should the prototype become a product.

A further advantage arises in relation to expertise. Clearly, electronics knowledge is essential for creating new hardware but many of the prototypes discussed in this paper did not require any. The knowledge needed was of 3D modelling and printing/laser-cutting, activities that are becoming familiar to contemporary DIY enthusiasts.

Last but surely not least is the very limited time needed to make a prototype. For example the whole process, from conception to devices selection, 3D modelling and printing the cases, composing and finish, took less than a week for the digital baubles developed in our first case study (Fig. 1) or the birdhouse in the second (Fig. 5).

Time, cost and expertise are fundamental factors for fast prototyping. The possibility to quickly give shape to one's ideas and try out many options during multiple iterations is an exciting perspective for designers who think with their hands and understand through making [3].

THREE TYPES OF FAST PROTOTYPES

Two case studies each with three prototypes created using existing devices or components (as opposed to bespoke ones) are used to illustrate our argument. While the first case study was used to lay the foundations of the process, the second validated it in a substantially different context. Using the same three types of hacked prototypes in a different project reinforced the feasibility of the chosen categories. In this section we outline the three types of prototype, before discussing the case studies themselves.

Embedding

Embedding a device involves inserting the entire device into a new form factor. By simply changing its context and shape, a device can gain a new interactive, tangible quality while preserving its basic functionality. The main challenge here is to map the controls to provide meaningful interactions, which requires little or no knowledge about the underlying technology.

Cracking it open

Sometimes the right technology is just hidden in another case or form. Taking it out of this case and using only the necessary parts in a new context enables fast prototype creation without the need for deeper technical understanding. Thus we create a new device by using some internal parts of an existing one.

Collating

Using multiple devices and combining the abilities of different technologies requires technical knowledge but allows us to test various scenarios without expensive, specialised hardware and keeps the design flexible for possible future modifications. Collating involves combining a number of existing technologies or devices to create a single more complex prototype. Some limited coding can also be done in order to create the desired interaction. This is likely to be based on reusing or modifying existing libraries or code that is available online. New code is written only as required by the design process.

Figure 1: A pocket-size digital photo frame is embedded in a photo bauble.

CASE STUDY 1: DIGITAL CHRISTMAS MEMORIES

Our first case study was in the context of digital Christmas memories bound to physical, interactive objects [8]. This was a new territory that we explored through prototypes.

Embedding

What was the design concept?

Our aim was to create digital baubles that captured and held personal media, such as a set of precious photos or the sound of past Christmas. They had to be small (hand size), extremely simple to use, easy to pass around and, ultimately, fun. The initial concept was of a bauble locked up until the 'right time' arrived to access the recorded content. The bauble indicated that the opening time was approaching by progressively increasing its glow day after day and unlocking only on the predefined date.

How did the prototype capture the concept?

When reflecting on the core features we intended to explore, it occurred to us that there were actually two of them: encasing personal content into objects and using the passing of time to create anticipation. This generated distinct prototypes, discussed along with other digital Christmas concepts in [15]. The image bauble concept encompassed capturing and playing. We spent some time thinking how we could have both but decided to start with the easiest (playing) and to discuss 'capturing' during the workshop with potential adopters. This directed our choice of device: photo cameras were expensive and needed more time and engineering expertise to hack; a digital photo frame offered the needed functionality (display personal content), while being low cost and ready to use (Fig. 1b).

As mentioned above, the pocket-sized photo frame spurred creativity. The small size of the screen, excellent for embedding into small objects, triggered the idea of using the magnifying property of a viewfinder. We loaded the photo frames with photos captured by the workshop participants during the field study carried out the previous Christmas [15]. This was essential for the participants to engage with the prototype at a deeper level.

What was learned from the prototype?

In the workshop, the bauble was displayed as part of a composition (Fig. 1c) and blended nicely with the environment as opposed to appearing to be an unfamiliar digital device. The participants engaged with the bauble and commented loudly on what they were looking at that no one else could see: there was much passing back and forth between members of the same family when trying to identify the person in the picture. The photo frame's play mode was set on automatic and this provoked much discussion on how to control the pace of display via natural gestures such as shaking. The bauble was also switched on before the workshop started so by the time we discussed it the battery had run out and we had to recharge it (through a USB cable connected to a PC) before we could proceed. This hiccup prompted a discussion on how to charge these devices, with options such as a pull cord or solar cell.

Cracking it open

Motivated by the feedback from the workshop, we made another digital bauble to be deployed at Christmas (Fig. 2).

What was the design concept?

We focused on sound as it was easier to find a device that records and plays sound rather than images. Also, even more than images, sound captures the feeling of the moment and prompts reminiscing in a deeper emotional way [5] as by this enthusiastic comment on a mock-up sound bauble (Fig. 1d): "*I love that – that would be such a family heirloom*".

How did the prototype capture the concept?

A dictaphone provided all the functions for this prototype. As soon as we received it, we realised that we would have to design the interaction around the dictaphone's control buttons and their positions. For instance, the delete button was located on the side of the device whereas the play, stop, record, forward and backward buttons were on the front. We then dropped the delete command to see how this affected its use during deployment.

We intentionally avoided using the screen of the dictaphone to emphasise the "opacity" of sound. The dictaphone also used a method of navigating through the recorded sounds that we did not like and did not want to incorporate into our prototype. Time was spent determining how to work around the constraints posed by the device, together with the best set of controls and how they fitted in a layout we liked. In the end the prototype had just four buttons (Fig. 2): play, stop, record, and next sound.

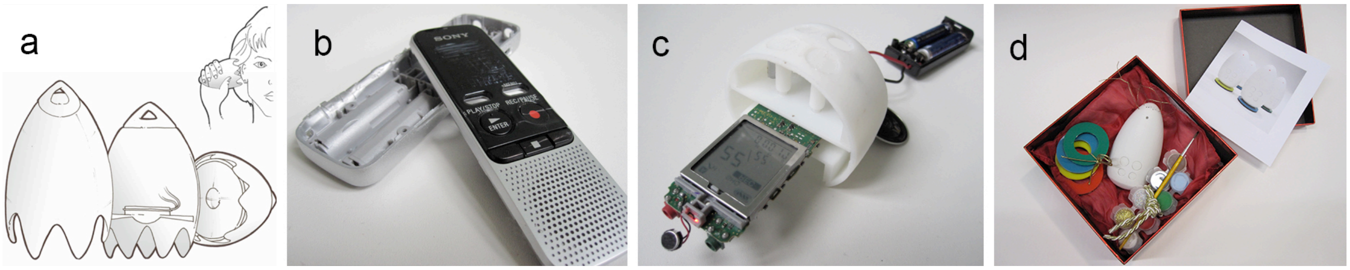

Figure 2: A Dictaphone provided the functionalities of a sound bauble. Mapping the buttons on the device required some thought.

What was learned through the prototype?
Sound baubles were given to five families for Christmas. To foster appropriation, they were delivered without any decoration but as a DIY toolkit (Fig. 2d). A one-page manual was included to explain the controls of the bauble.

Feedback from users was rich and varied. What is particularly interesting here is the reaction to the lack of a 'delete' function and the navigation through sounds being limited to 'next'. Finding *"the nice sound I know is there"* from among hundreds snippets proved difficult with navigation limited to just the 'next' control. The missing 'delete' function pushed a family to carefully plan what to record as they did not want to end up with many meaningless recordings. Similar comments were made by the families with small children who made many identical recordings. Many sound pranks occurred in the family with teenagers, whose parents were anxious to erase them. Making the 'delete' function available but difficult to access is worth exploring, as the pranks could feel different in a few years, when seen from a nostalgic point of view.

Collating

What was the design concept?
Much insight was gained through the previous prototypes and we wanted to capture some of the new ideas that these prototypes inspired: to split the record and play functions and to make the recording component small enough to be taken anywhere but limited to just one sound clip. In this case we decided that playback would occur on a different device where multiple recording cartridges could be docked and played in sequence (Fig. 3a). The cartridges can be personalized. This supports locating a specific recording, as it makes the mapping between the cartridge and the sound it contains explicit. The order of play can be changed each time by simply shuffling the cartridges.

How did the prototype capture the concept?
The core element of this concept is the separation of recording and playback functions. For this we needed to lower our level of hacked prototyping and use an off-the-shelf sound-recording board. We also used this opportunity to try out autonomously powering the device through solar cells. As in the previous cases, we had to work around constraints of the chosen device and this stimulated our creativity. In particular, the prototype must be set by the user to either play or record mode; this setting determines the outcome of the subsequent command. In the prototype the sound-board is set to play by default and switching between the two modes is triggered by placing a magnet on the cartridge to enable recording.

What was learned through the prototype?
This prototype highlighted the issue of quality as the sound from the board was too poor and not acceptable for deployment. The form as well was a dead end: to accommodate the solar panel a square shape was forced in a design that was intended to be a more graceful round shape. However the making of the cartridges increased our understanding of 'pocket-memories' and opened up new interaction options, such as encasing the magnet on a necklace that must be placed on the cartridge to record.

CASE STUDY 2: INTERACTIVE CEMETERY
The second case study explored concepts in an historical cemetery as part of the meSch project [16]. While for the Christmas study the prototypes were sequential, each stemming from previous findings, here we explored concepts in parallel broadening our experimentation with forms and interaction from the start.

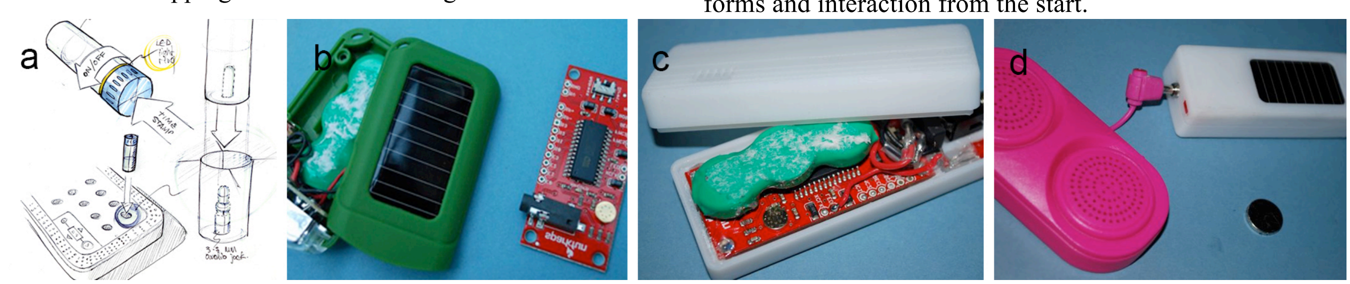

Figure 3: A sound record/play board, a solar cell battery charger, a push button and a magnetic switch were used in this prototype.

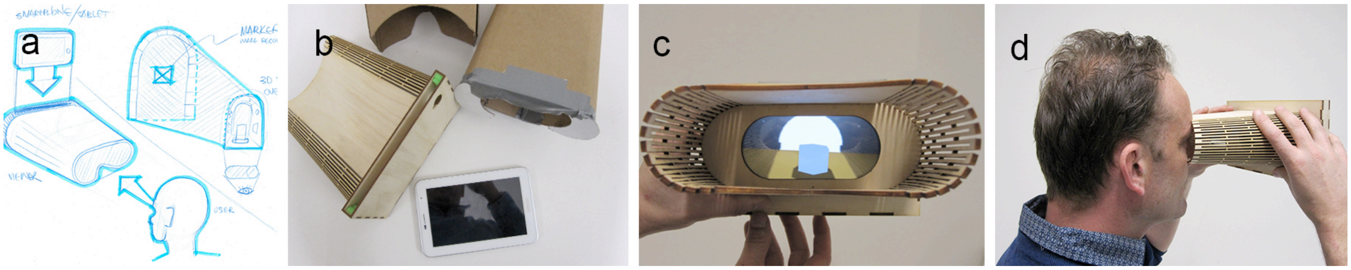

Figure 4: By embedding a tablet in a form resembling binoculars we create an augmented reality view of the past.

Embedding

What was the design concept?

Many of the visitors to the cemetery are unaware that the place is, in fact, a cemetery as a large section has been converted to parkland. Most people come not to visit graves but to exercise, eat lunch, or walk their dogs. From the main paths through this park some areas of the cemetery (such as the catacombs) are visible, but there are no real clues supplied as to their purpose or history. We aimed to expose the visitors to some of this information in an engaging way.

How did the prototype capture the concept?

Augmented reality is becoming commonplace on tablets: by embedding a tablet device in a custom case that resembled a set of binoculars we push visitors to look at a familiar space in a different way (Fig. 4). What they see is the cemetery as it is now overlaid with a digital reconstruction of historical views. For instance, areas of the cemetery that have been cleared show the lawn full with gravestones. Visitors can also "look inside" sealed structures such as catacombs or see the original procession path, later covered by burials.

What was learned through the prototype?

Different forms, initially in cardboard then in laser-cut plywood (Fig. 4b) were tried out and these led to a number of considerations. By just hiding the controls and only showing the display area the embedded tablet loses its original feel and becomes a new device. This new device is suitable for any technical ability as its binoculars form affords the well-known behaviour of exploring the surrounding area by sight, focussing the attention of the watcher on what is there.

The form changes the interaction: the encasing creates darkness essential to see a screen outdoor (Fig. 4c); it also provides an optimal distance and angle of view (Fig. 4d). The integration of form (the binoculars) and function (the tablet) was not without obstacles: we wanted to embed the tablet completely (Fig. 4a) but such an enclosure for the Samsung Galaxy Tab 2.0 that we used would be too large to be comfortably handled. A compromise was found: a box holding the tablet is fixed to a visor. However as the resulting display area is much smaller than the tablet's screen size we are now considering swapping it for a smartphone that would fit our initial design.

Cracking it open

What was the design concept?

As already mentioned many visitors use the cemetery as a shortcut, for a lunch stroll or as a place to walk their dog. They cross the landscape at their own pace generally following the same path. We wanted to encroach on the walkers' path in order to cause them to stop, engage and interact with that part of the cemetery. A key factor for this concept was that it must activate based on the presence of a visitor who is not carrying any specific triggering device. The design also had to be sympathetic to the landscape and unobtrusive in its form factor. The resulting prototype was a birdhouse (Fig. 5a) that is activated by a visitor's presence and projects a pattern of flying birds onto the ground to capture their attention.

How did the prototype capture the concept?

The effect we aimed to achieve is very close to that of musical projection devices for babies that are currently available on the market. One such device was dismantled (Fig. 5b) in order to remove the projection and image rotation unit. A new picture wheel for the projection of bird silhouettes and a new housing resembling a bird box were created in order to produce a prototype that blends into the landscape. The concept of the birdhouse is of a device augmenting the environment in a permanent way. We also considered how to self-power it: a Nickel-Metal Hydride battery and a solar cell taken from a consumer solar-powered led torch were encased on the birdhouse roof.

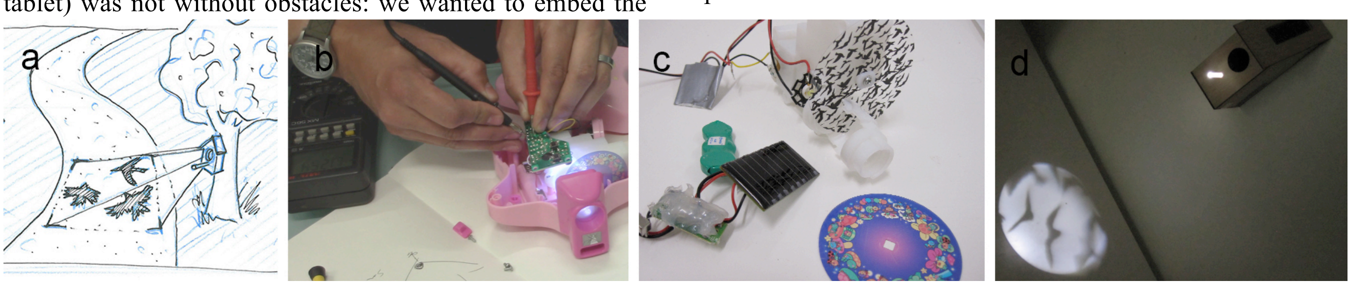

Figure 5: A hacked children's light and sound toy allows us to create a low cost projector prototype.

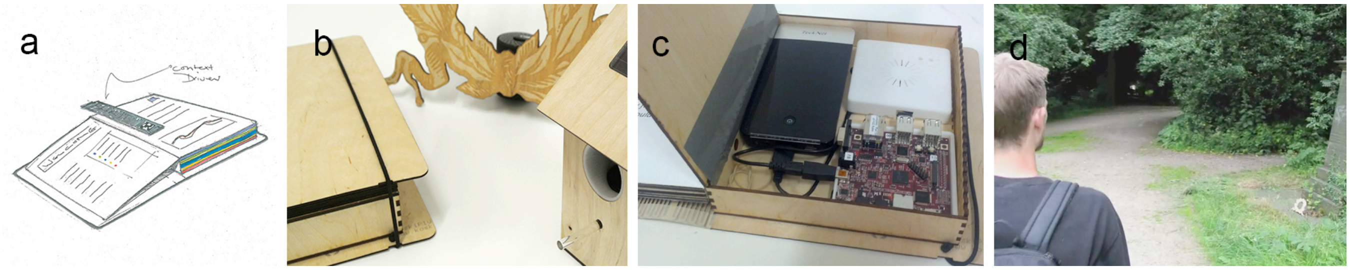

Figure 6: An embedded computer and a Bluetooth speaker create interactive location-based audio in the cemetery.

What was learned through the prototype?
The low-tech LED and lens technology from the toy proved too weak for projection in daylight or over a long distance. However, as a proof of concept, the prototype was successful and well-received when proposed to the volunteers of the cemetery trust. It prompted interesting discussions ranging from the importance of illuminating a path at night to the possibility of changing the projection on a seasonal base to highlight how the cemetery landscape changes.

It is clearly possible to overcome the current limitation by using a pocket projector controlled via a card-size computer. However the complexity and cost increase reducing the value of this concept for its final destination, a public park where vandalism may occur.

Collating

What was the design concept?
Cemeteries are full of stories: the lives of people from all walks of life can be told in place, offering new perspectives and elements for reflection on the changes that have occurred in society. To take advantage of the evocativeness of the cemetery we envisaged that the place itself could tell the stories: nearby visitors are attracted to a point of interest, such as a particular gravestone, by a sound; if they approach closer a snippet of the story is told. Every point may have multiple stories, such as the different lives of the members of a family all buried in the same place, the social meaning of an epitaph ("the wreck of her husband") or the artistic value of a sculpture. Visitors can freely walk the cemetery following their own mood and choose the type of story they want to listen to at any point in time.

How did the prototype capture the concept?
The core element of the concept is of the narrative to be local to a place. Bluetooth loudspeakers offered the desired functionality: they have a unique identifier (that we can associate to a place) and can play the sound transmitted by a Bluetooth-connected device. The first prototype used the evocative form of a Victorian apothecary bag to host the transmitter device, but the selection of the type of story by moving a bottle in a different slot was not convincing. The second prototype builds upon the natural interaction with a book (Fig. 6a): each page shows a different perspective (e.g. medical advancement, social history, personal life) and the visitor selects the type of story by placing a bookmark on a particular page. The Bluetooth loudspeakers are hidden in elements that fit the environment (a wreath and a birdhouse, Fig. 6b).

A battery-powered hand-sized computer-on-a-board system (Beagleboard) was combined with a USB Bluetooth dongle (Fig. 6c) to create a wireless link between the board itself and Bluetooth speakers which were positioned at the points of interest. The embedded system contained all the stories in the form of audio files. Different audio files are played depending on where the visitor is: a visitor's location is determined from the Bluetooth loudspeaker's in-built MAC address (each loudspeaker is mapped onto a place of interest), while the measure of the Bluetooth signal strength provides an estimate of how far the visitor is thus controlling the playing of a sound to attract interest or to narrate a story.

Independent powering offers the chance to easily explore outdoor locations and catch impressions of the real interaction in space and the effect of audio output in an open environment.

What was learned through the prototype?
Bluetooth-based distance measurement and timing issues turned out to be big challenges in realizing the concept. The large influence of the environment on Bluetooth signal strength made it difficult to find a set-up that worked reliably everywhere in the cemetery. Obstacles, other devices and even height above the ground affected the signal strength. Finding timing that works well in different situations and for different walking speeds was also an issue. While the signal strength problem is present in every wireless technology, many of the timing problems came from the limitations of Bluetooth technology with regard to searching for devices, pairing and establishing a connection.

A video recording the interaction of attracting and storytelling in place (Fig. 5d) was shown to the cemetery volunteers in a workshop and was very well received: the idea of the deceased or their family telling the story was powerful and emotionally charged. Interesting comments were made on the possibility of creating stories that connected many places and many people, possibly those who worked together or who funded charities and schools. Participants also discussed the effect of different media with audio being potentially intrusive but also potentially intriguing for other people passing by.

FAST PROTOTYPING TANGIBLE INTERACTION

The Process

Reflecting on our experience we see five steps in fast prototyping as a mean to explore new areas of tangible interaction: formulating a concept, selecting the technology, designing the form, critically evaluate the outcome and reflect on the findings.

The starting point is *a concept*: decide what the most interesting aspect to explore is, as the prototype will focus solely on that. Decomposing the concept to the core elements is also a way of clarifying what the designers want to do and why. Clearly, this is a process of pruning and one should be prepared to forgo some important aspects, which may be picked up again at a later stage.

Once the concept has been determined, the next step is the *selection of existing technology*. This step requires much comparison and some decision-making that will affect the prototype. For example, when selecting the dictaphone that would become the core element of the sound bauble (Fig. 2), considerations of sound quality, recording time, frequency and method of charging influenced our final choice. Similarly for the book (Fig. 6) the decision of using a Beagleboard and a large battery pack affected the size of the book. We could have probably scaled down in size, for example by using a Raspberry PI, but familiarity with the other hardware and software made the Beagleboard more attractive for fast prototyping.

Deciding on *the form factor* is the next step. Although some ideas may have been sketched at concept generation, the final form has to take into account the technology. The main issue is likely to be how to map the intended interaction onto the device controls. For example, in the case of the sound bauble (Fig. 2) much work was involved in figuring out how to activate the touch buttons on the dictaphone and how to space them out. In the case of the book (Fig. 6) several methods were investigated in order to find a simple way to select different types of stories. An interesting phenomenon in the design of the form is the inspiration that comes when facing technology constraints, as with the small photoframe (Fig. 1b) which changed from a ball that can be open to one to look into.

As discussed above, the purpose of fast prototypes is to advance our understanding, improve the communication of ideas and progress toward the optimal solution quickly and effectively. As such prototypes can be used by the team in different ways: to provoke discussion with potential adopters (Fig. 1, Fig. 5); to check the technical feasibility of a specific interaction (Fig. 3); to investigate how the form affects the technology (Fig. 4); to gain feedback on appropriation and use (Fig. 2, Fig. 6). All are forms of *evaluation* that trigger *reflection* on what works and what needs reconsidering. However, if the prototype is going to be evaluated with potential adopters, then the form must be polished to make it fit the context and support a better communication of the envisaged used.

Guidelines and Tips

The process for fast prototyping described above gives an overall framework, but in our experience, other elements have also proved important. Here we share some guidelines and tips that other researcher may find useful.

Watch your environment: There are many ubiquitous technologies out there from movement sensors for automatic outdoor lighting to singing greeting cards. Also the ever-increasing range of apps makes smart phones and tablets a potential source of (almost) already-made functionalities that can be exploited for fast prototyping. Search for the simplest solution first.

Inspect toys: Many toys contain low cost sensing and presentation technology that can be used for simple interactions. An example of this is our birdhouse projector, which was based on a light and sound show toy designed for young children. As unprofessional as this can sound, it is one of the strategies adopted by professional inventors while exploring new ideas [8].

Be quick, be focussed: Ideas are ephemeral so fix your intuitions in a prototype now. Keeping the flow of creativity going is more important that perfection: fast prototyping allows to make, to learn, and to move on.

Take a look at toolkits: Flexible, extensible platforms such as Arduino or Gadgeteer cover a range of programmable sensor and actuator technologies that can be used to build a variety of prototypes. While most of the prototypes discussed in this paper have not involved such technology, sometimes they offer the quickest path to a useful prototype.

Keep it simple: When developing a prototype to explore the form and interaction of a device it is the overall impression of the prototype that is important. Accuracy and reliability are less relevant at this stage: when testing a prototype one can control and fit the conditions of the test to the benefit of the prototype.

Function follows form: Dressing up devices in an appropriate shape covers the original purpose of the technology used and allows exploration of the concept itself. The proliferation of desktop laser cutting and 3D printing makes this easier than ever before. By hiding the technology we focus our and the adopters' attention more fully on the interaction rather than how it works.

Think about energy: Power supply is especially critical for portable devices. This aspect has to be foreseen when designing cases and shapes. Having to recharge may limit how the prototype can be used, both during evaluation and in actual use. However, there can be some scope for creativity in how the device can be powered or charged, as was the case for the recording cartridge or the birdhouse.

Someone has done it before: The Maker movement and the popularity of venues such as *Make* magazine and *Instructables.com* mean that there are a large number of resources available on hacking existing devices. This is also the case with many toolkits, for which you can often find helpful code snippets or even whole libraries. Similarly, many interactions can be simulated with smartphones either by writing new programs or using readily available apps.

CONCLUSIONS

We do not see the types of prototypes discussed here as alternatives to sketching or cardboard prototypes that can be constructed on the spot during any creative session. In their ethos hacked prototypes intend to bring to the fore the material form and the effect it has on interaction: the feeling when holding the object, the physical engagement with it, and the appropriation engendered by possessing one are insights provided only by 'the real thing'. For this to occur the prototype must have been designed with the value of aesthetic in mind and with enough technology to evoke aspects of final use in a convincing way. As such these prototypes embody the designer's tacit knowledge on which product or interaction will work in that context and enable to communicate across different expertise and with users. Prototypes of the kind we propose are a physical approximation of ideas and elicit a visceral reaction, an important feedback in the early stages to (re)orient design.

Although physical prototyping by using existing technology does not need many resources, the devices and electronics chosen pose constraints on the form, quality, functionality, and control. This can be seen in a negative way or as a positive inspiration for new solutions. Recognizing that a path leads to a dead end is a positive step in the construction of the understanding and knowledge needed to progress particularly when exploring new territories for which previous experience is very limited. Sketches, mockups and multiple prototypes may seem to slow down the process, but they actually generate results faster as it is highly unlikely that the best solution is the first (or only) idea. Interesting problems are complex, and a series of early experimentations is often the best way to decide among competing directions. The faster we make our idea tangible, the sooner we will be able to evaluate them, refine them, and move toward the best solution.

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REFERENCES

1. Baskinger, M., Gross, M. Tangible Interaction = Form + Computing. *Interactions*, Jan + Feb, ACM Press (2010), 6-11.
2. Brandt, J. et al. Opportunistic Programming: Writing Code to Prototype, Ideate, and Discover. *IEEE Software*, Sept/Oct (2009), 18-24.
3. Brown, T. *Change by design*. Harper, (2009).
4. Buechley, L., Perner-Wilson, H. Crafting Technology: Reimagining the Process, Materials, and Cultures of Electronics. *TOCHI*, ACM Press (2012) 19 (3).
5. Dib, L. Petrelli, D. Whittaker, S. Sonic Souvenirs: Exploring the paradoxes of recording sounds for family remembering. *Proc. CSCW 2010*, ACM Press (2010)
6. Floyd, C. A Systematic Look at Prototyping. In Budde, R. et al. (eds) "Approaches to Prototyping", *Springer Verlag*, (1984), 1-18.
7. Greenberg, S., Boyle, M. Customizable Physical Interfaces for Interacting with Conventional Applications. *Proc. UIST 2002*, ACM Press (2002).
8. Hartmann, B., Doorley, S., Klemmer, S. Hacking, Mashing, Gluing: Understanding Opportunistic Design. *Pervasive Computing*, July-Sept 2008, 46-54.
9. Hornecker, E. Beyond Affordance: Tangibles' Hybrid Nature. *Proc. TEI 2012*, ACM Press (2012), 173-182.
10. Hornecker, E., Buur, J. Getting a Grip on Tangible Interaction: A Framework on Physical Space and Social Interaction. *Proc. CHI 2006*, ACM Press (2006), 437-446.
11. Hornecker, E., Psik, T. Using ARToolKit Markers to Build Tangible Prototypes and Simulate Other Technologies. *Proc. Interact 2005*, (2005)
12. Houde, S., Hill, C. What do prototypes prototype? In Helander, Landauer, Prabhu (eds.) *Handbook of Human Computer Interaction*, (2nd Ed) Elsevier Science, (1997).
13. Hudson, S., Mankoff, J. Rapid Construction of Functioning Physical Interfaces from Cardboard, Thumbtacks, Tin Foil and Masking Tape. *Proc. UIST 2006*, ACM Press (2006),
14. Moggridge, B. *Designing Interactions*. MIT press, (2007)
15. Petrelli, D., Bowen, S., Light, A., Dulake, N. Digital Christmas: An exploration of festive technology. Proc. of Designing Interactive Systems – *Proc. DIS 2012*, ACM Press (2012).
16. Petrelli, D. et al. A. Integrating Material and Digital: A New Way for Cultural Heritage. *Interactions*, July + August, ACM Press, (2013).
17. Schmidt, A., Bial, D. Phones and MP3 Players as the Core Components in Future Appliances. *IEEE Pevasive Computing*, 10 (2), (2011), 8-11.
18. Weichel, C., Lau, M., Gallersen, H. Enclosed: A Component-Centric Interface for Designing Prototype Enclosures. *Proc. TEI 2013*, ACM Press (2013).

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